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(54) **AUTOMATIC REGISTRATION**

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G06F 17/30 (2006.01)
G06K 9/46 (2006.01)
G06T 17/20 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 17/30247*** (2013.01); ***G06F 17/3053*** (2013.01); ***G06F 17/30598*** (2013.01); ***G06K 9/46*** (2013.01); ***G06T 17/20*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 17/30247; G06F 17/30256; G06K 9/46; G06T 17/20; G06T 19/20; G06T 2200/08
USPC 707/737
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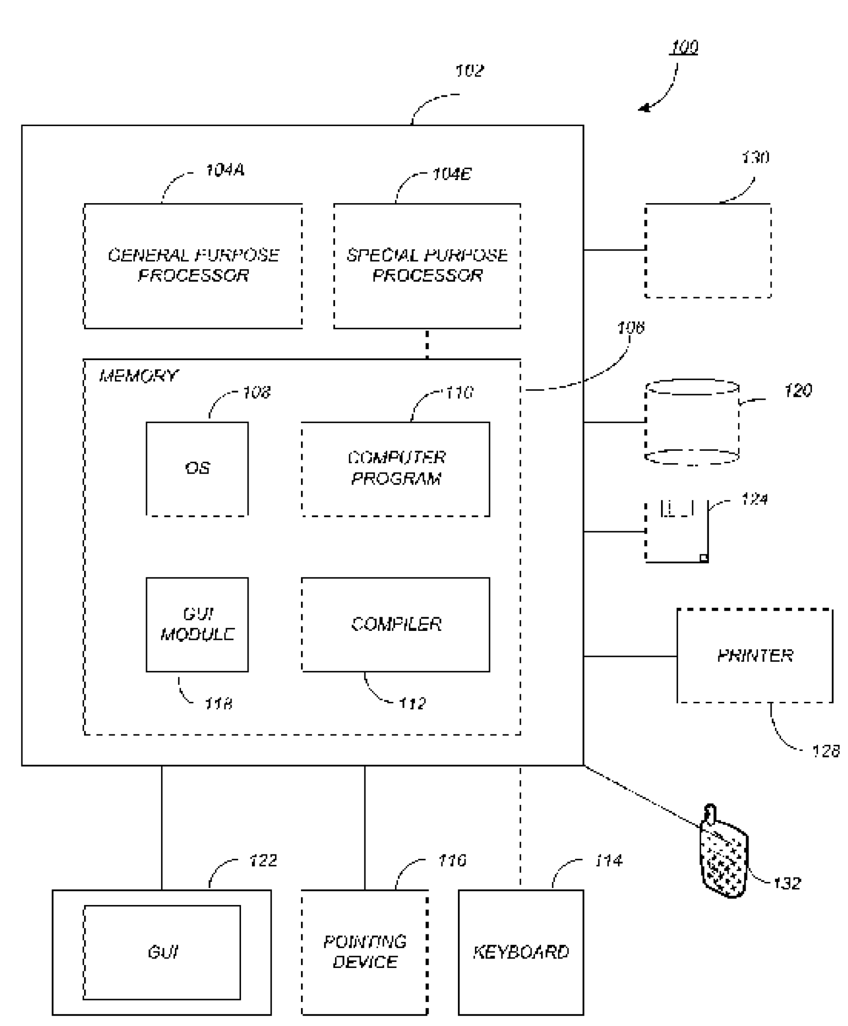
(57) **ABSTRACT**

A method, system, apparatus, article of manufacture, and computer-readable storage medium provide the ability to merge multiple point cloud scans. A first raw scan file and a second raw scan file (each including multiple points) are imported. The scan files are segmented by extracting segments. Features are extracted from the segments. A set of candidate matching feature pairs are acquired by registering/matching/pairing features from one scan to features from another scan. The candidate pairs are refined based on an evaluation of all of the matching pairs. The candidate pairs are further refined by extracting sample points from the segments (within the matched pairs) and refining the pairs based on the points. The feature pairs are scored and then merged based on the scores.

28 Claims, 3 Drawing Sheets



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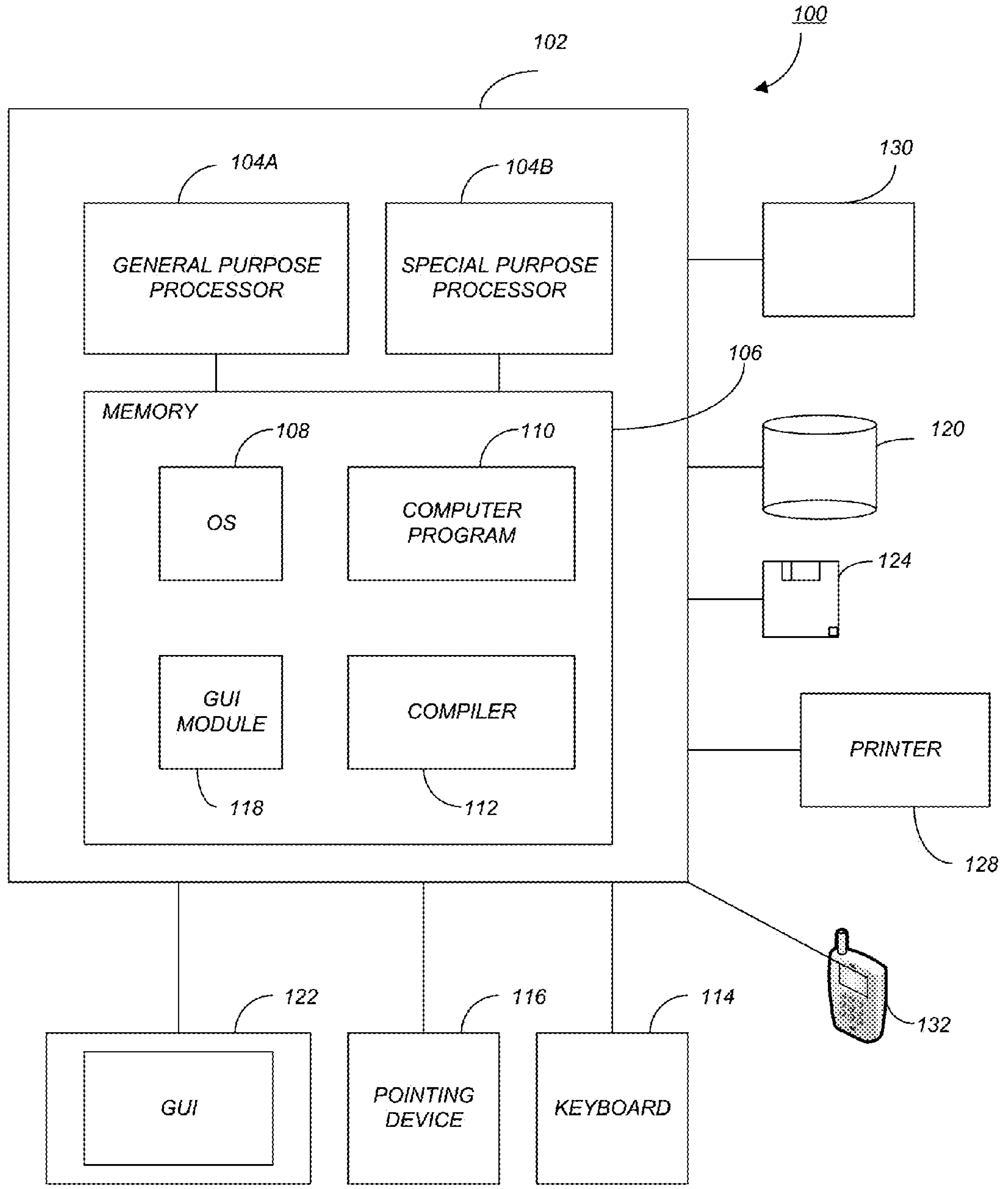
100
102
104A
104B
GENERAL PURPOSE PROCESSOR
SPECIAL PURPOSE PROCESSOR
130
106
MEMORY
108
110
OS
COMPUTER PROGRAM
120
124
GUI MODULE
COMPILER
PRINTER
118
112
128
132
122
116
114
GUI
POINTING DEVICE
KEYBOARD

FIG. 1

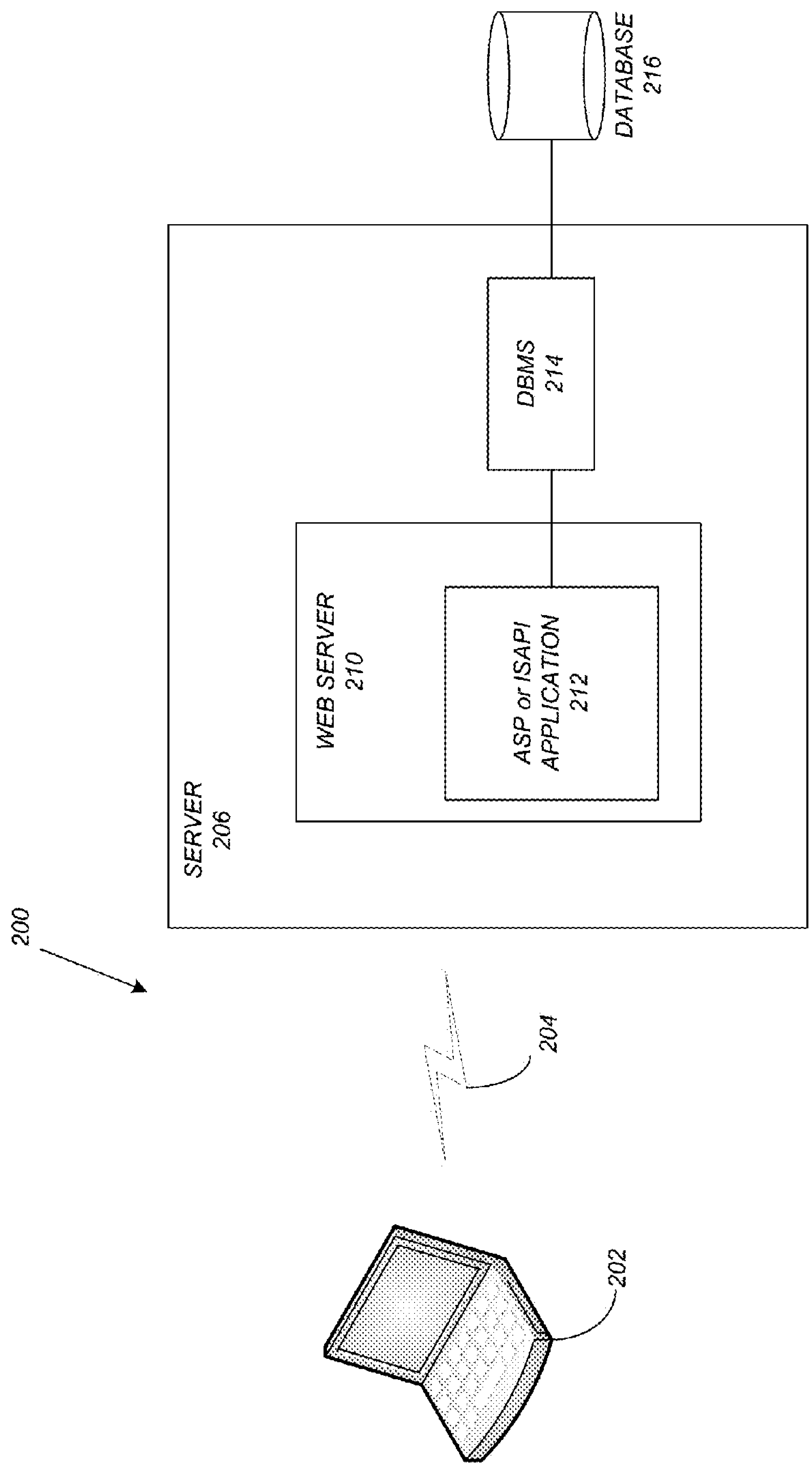
DATABASE
216
DBMS
214
WEB SERVER
210
ASP or ISAPI
APPLICATION
212
SERVER
206
200
204
202

FIG. 2

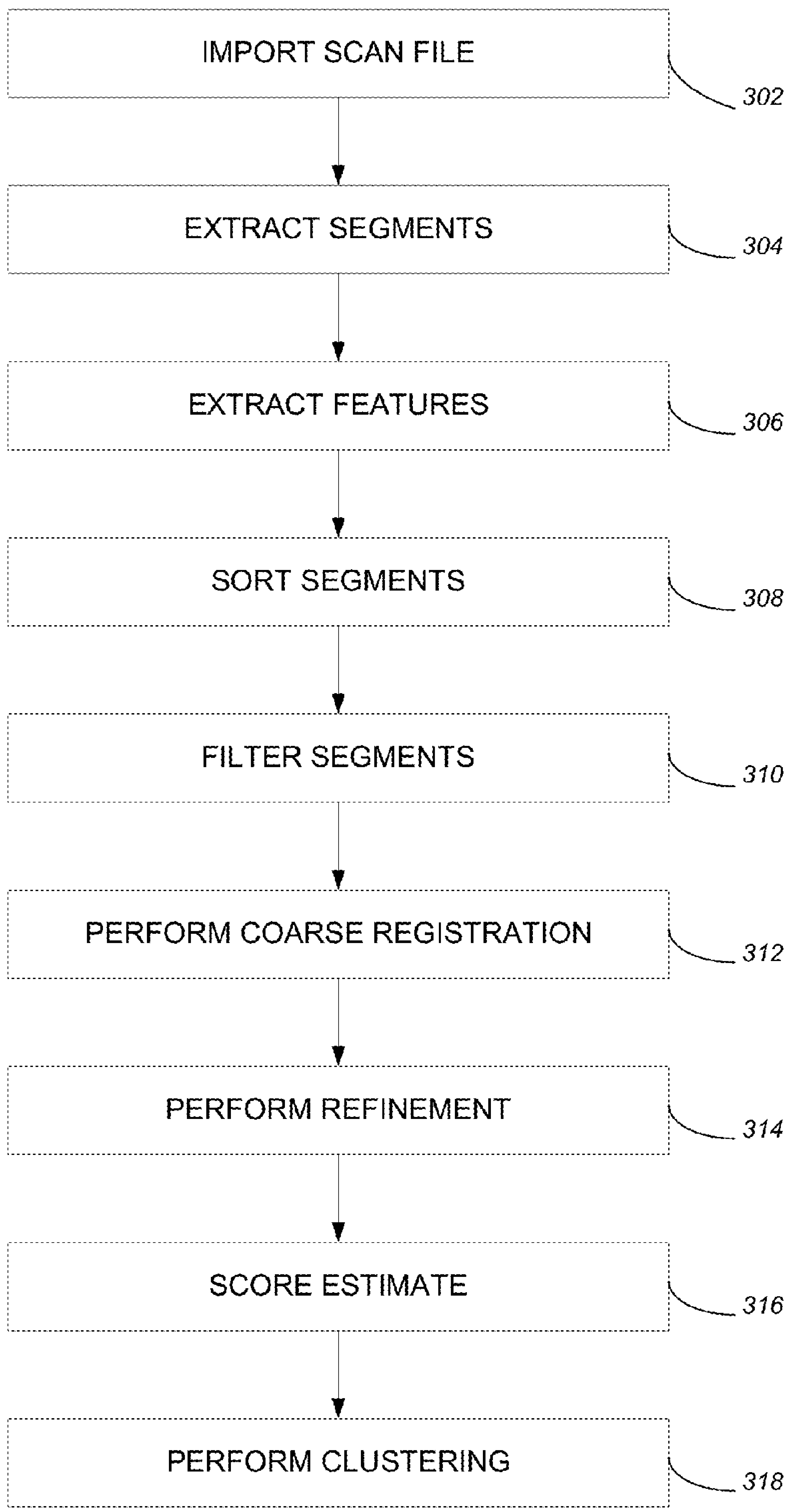
IMPORT SCAN FILE
302
EXTRACT SEGMENTS
304
EXTRACT FEATURES
306
SORT SEGMENTS
308
FILTER SEGMENTS
310
PERFORM COARSE REGISTRATION
312
PERFORM REFINEMENT
314
SCORE ESTIMATE
316
PERFORM CLUSTERING
318

FIG. 3

AUTOMATIC REGISTRATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. Section 119(e) of the following and commonly-assigned U.S. provisional patent application(s), which is/are incorporated by reference herein:

Provisional Application Ser. No. 61/910,698, filed on Dec. 2, 2013, by Oytun Akman, Ronald Poelman, and Seth Koterba, entitled "Automatic Registration".

This application is related to the following co-pending and commonly-assigned patent application, which application is incorporated by reference herein:

U.S. patent application Ser. No. 14/536,266, entitled "PRE-SEGMENT POINT CLOUD DATA TO RUN REAL-TIME SHAPE EXTRACTION FASTER", by Ronald Poelman and Oytun Akman, filed on Nov. 7, 2014, which application claims the benefit under 35 U.S.C. Section 119(e) of Provisional Application Ser. No. 61/901,069, filed on Nov. 7, 2013, by Ronald Poelman and Oytun Akman, entitled "Pre-Segment Point Cloud Data to Run Real-Time Shape Extraction Faster,"; and

U.S. patent application Ser. No. 14/536,232, entitled "OCCLUSION RENDER MECHANISM FOR POINT CLOUDS", by Paulus Jacobus Holverda and Ronald Poelman, filed on Nov. 7, 2014, which application claims the benefit under 35 U.S.C. Section 119(e) of Provisional Application Ser. No. 61/901,067, filed on Nov. 7, 2013, by Paul Holverda and Ronald Poelman, entitled "Occlusion Render Mechanism for Point Clouds."

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to point cloud data, and in particular, to a method, apparatus, and article of manufacture for automatically registering/merging different scans of point cloud data.

2. Description of the Related Art

Point cloud data is often acquired using laser scans of an area. It is often not possible to utilize a single scan to capture the desired area/structure. Thus, multiple laser scan range images (i.e., panoramic representations with a depth component) may be utilized to capture a desired area/structure. However, each scan has a unique vantage point and the different scans do not know where they are with respect to each other. It is desirable to determine how such scans overlap/align with each other in coordinate space. In other words, one scan may have some measurements (e.g., the distance between the wall and floor, etc.). However, the one scan may not cover the whole distance of an object/area (e.g., a building). If the multiple scans are aligned, the measurement of the full length of the area (e.g., building) may be determined. Embodiments of the invention attempt to automatically register the different scans together to create a single image that includes multiple accurately aligned scans.

SUMMARY OF THE INVENTION

Embodiments of the invention align multiple scans into a single coordinate space in a geometric manner. Scans are imported. The imported scans are segmented. The segments that have certain geometric attributes (e.g., planar) are used as input for a registration process (i.e., the segments that are used as input are filtered such that a subset of the segments are processed through the system). The system then searches the segments for matches to determine the proper alignment.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIG. **1** is an exemplary hardware and software environment used to implement one or more embodiments of the invention;

FIG. **2** schematically illustrates a typical distributed computer system using a network to connect client computers to server computers in accordance with one or more embodiments of the invention; and

FIG. **3** illustrates the logical flow for automatically registering scans in accordance with one or more embodiments of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following description, reference is made to the accompanying drawings which form a part hereof, and which is shown, by way of illustration, several embodiments of the present invention. It is understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

Hardware Environment

FIG. **1** is an exemplary hardware and software environment **100** used to implement one or more embodiments of the invention. The hardware and software environment includes a computer **102** and may include peripherals. Computer **102** may be a user/client computer, server computer, or may be a database computer. The computer **102** comprises a general purpose hardware processor **104**A and/or a special purpose hardware processor **104**B (hereinafter alternatively collectively referred to as processor **104**) and a memory **106**, such as random access memory (RAM). The computer **102** may be coupled to, and/or integrated with, other devices, including input/output (I/O) devices such as a keyboard **114**, a cursor control device **116** (e.g., a mouse, a pointing device, pen and tablet, touch screen, multi-touch device, etc.) and a printer **128**. In one or more embodiments, computer **102** may be coupled to, or may comprise, a portable or media viewing/listening device **132** (e.g., an MP3 player, iPod™, Nook™, portable digital video player, cellular device, personal digital assistant, etc.). In yet another embodiment, the computer **102** may comprise a multi-touch device, mobile phone, gaming system, internet enabled television, television set top box, or other internet enabled device executing on various platforms and operating systems.

In one or more embodiments, computer **102** is communicatively coupled to, or may comprise, a laser scanner **134**. Such a laser scanner **134** may consist of a field measurement device capable of producing a three-dimensional (3D) representation of present conditions through the collection of individually measured points. The set of all points collected and registered with another after the scanning process is referred to as a point cloud. Such a point cloud may be stored in data storage devices **120**/**124**, within the scanner **134**, in memory **106**, and/or in any other device capable of storing such information. The laser scanner **134** may utilize a variety of scanning methods including aerial, static, and mobile. Such laser scanning may scan millions of point in seconds without climbing on equipment and/or conducting contact measurements.

In one embodiment, the computer **102** operates by the general purpose processor **104**A performing instructions defined by the computer program **110** under control of an operating system **108**. The computer program **110** and/or the operating system **108** may be stored in the memory **106** and may interface with the user and/or other devices to accept input and commands and, based on such input and commands and the instructions defined by the computer program **110** and operating system **108**, to provide output and results.

Output/results may be presented on the display **122** or provided to another device for presentation or further processing or action. In one embodiment, the display **122** comprises a liquid crystal display (LCD) having a plurality of separately addressable liquid crystals. Alternatively, the display **122** may comprise a light emitting diode (LED) display having clusters of red, green and blue diodes driven together to form full-color pixels. Each liquid crystal or pixel of the display **122** changes to an opaque or translucent state to form a part of the image on the display in response to the data or information generated by the processor **104** from the application of the instructions of the computer program **110** and/or operating system **108** to the input and commands. The image may be provided through a graphical user interface (GUI) module **118**. Although the GUI module **118** is depicted as a separate module, the instructions performing the GUI functions can be resident or distributed in the operating system **108**, the computer program **110**, or implemented with special purpose memory and processors.

In one or more embodiments, the display **122** is integrated with/into the computer **102** and comprises a multi-touch device having a touch sensing surface (e.g., track pod or touch screen) with the ability to recognize the presence of two or more points of contact with the surface. Examples of multi-touch devices include mobile devices (e.g., iPhone™, Nexus S™, Droid™ devices, etc.), tablet computers (e.g., iPad™, HP Touchpad™), portable/handheld game/music/video player/console devices (e.g., iPod Touch™, MP3 players, Nintendo 3DS™, PlayStation Portable™, etc.), touch tables, and walls (e.g., where an image is projected through acrylic and/or glass, and the image is then backlit with LEDs).

Some or all of the operations performed by the computer **102** according to the computer program **110** instructions may be implemented in a special purpose processor **104**B. In this embodiment, some or all of the computer program **110** instructions may be implemented via firmware instructions stored in a read only memory (ROM), a programmable read only memory (PROM) or flash memory within the special purpose processor **104**B or in memory **106**. The special purpose processor **104**B may also be hardwired through circuit design to perform some or all of the operations to implement the present invention. Further, the special purpose processor **104**B may be a hybrid processor, which includes dedicated circuitry for performing a subset of functions, and other circuits for performing more general functions such as responding to computer program **110** instructions. In one embodiment, the special purpose processor **104**B is an application specific integrated circuit (ASIC).

The computer **102** may also implement a compiler **112** that allows an application or computer program **110** written in a programming language such as COBOL, Pascal, C++, FORTRAN, or other language to be translated into processor **104** readable code. Alternatively, the compiler **112** may be an interpreter that executes instructions/source code directly, translates source code into an intermediate representation that is executed, or that executes stored precompiled code. Such source code may be written in a variety of programming languages such as Java™, Perl™, Basic™, etc. After completion, the application or computer program **110** accesses and manipulates data accepted from I/O devices and stored in the memory **106** of the computer **102** using the relationships and logic that were generated using the compiler **112**.

The computer **102** also optionally comprises an external communication device such as a modem, satellite link, Ethernet card, or other device for accepting input from, and providing output to, other computers **102**.

In one embodiment, instructions implementing the operating system **108**, the computer program **110**, and the compiler **112** are tangibly embodied in a non-transitory computer-readable medium, e.g., data storage device **120**, which could include one or more fixed or removable data storage devices, such as a zip drive, floppy disc drive **124**, hard drive, CD-ROM drive, tape drive, etc. Further, the operating system **108** and the computer program **110** are comprised of computer program **110** instructions which, when accessed, read and executed by the computer **102**, cause the computer **102** to perform the steps necessary to implement and/or use the present invention or to load the program of instructions into a memory **106**, thus creating a special purpose data structure causing the computer **102** to operate as a specially programmed computer executing the method steps described herein. Computer program **110** and/or operating instructions may also be tangibly embodied in memory **106**, data storage device **120**/**124** and/or data communications devices **130**, thereby making a computer program product or article of manufacture according to the invention. As such, the terms "article of manufacture," "program storage device," and "computer program product," as used herein, are intended to encompass a computer program accessible from any computer readable device or media.

Of course, those skilled in the art will recognize that any combination of the above components, or any number of different components, peripherals, and other devices, may be used with the computer **102**.

FIG. **2** schematically illustrates a typical distributed computer system **200** using a network **204** to connect client computers **202** to server computers **206**. A typical combination of resources may include a network **204** comprising the Internet, LANs (local area networks), WANs (wide area networks), SNA (systems network architecture) networks, or the like, clients **202** that are personal computers or workstations (as set forth in FIG. **1**), and servers **206** that are personal computers, workstations, minicomputers, or mainframes (as set forth in FIG. **1**). However, it may be noted that different networks such as a cellular network (e.g., GSM [global system for mobile communications] or otherwise), a satellite based network, or any other type of network may be used to connect clients **202** and servers **206** in accordance with embodiments of the invention.

A network **204** such as the Internet connects clients **202** to server computers **206**. Network **204** may utilize ethernet, coaxial cable, wireless communications, radio frequency (RF), etc. to connect and provide the communication between clients **202** and servers **206**. Clients **202** may execute a client application or web browser and communicate with server computers **206** executing web servers **210**. Such a web browser is typically a program such as MICROSOFT INTERNET EXPLORER™, MOZILLA FIRE-

FOX™, OPERA™, APPLE SAFARI™, GOOGLE CHROME™, etc. Further, the software executing on clients **202** may be downloaded from server computer **206** to client computers **202** and installed as a plug-in or ACTIVEX™ control of a web browser. Accordingly, clients **202** may utilize ACTIVEX™ components/component object model (COM) or distributed COM (DCOM) components to provide a user interface on a display of client **202**. The web server **210** is typically a program such as MICROSOFT'S INTERNET INFORMATION SERVER™.

Web server **210** may host an Active Server Page (ASP) or Internet Server Application Programming Interface (ISAPI) application **212**, which may be executing scripts. The scripts invoke objects that execute business logic (referred to as business objects). The business objects then manipulate data in database **216** through a database management system (DBMS) **214**. Alternatively, database **216** may be part of, or connected directly to, client **202** instead of communicating/obtaining the information from database **216** across network **204**. When a developer encapsulates the business functionality into objects, the system may be referred to as a component object model (COM) system. Accordingly, the scripts executing on web server **210** (and/or application **212**) invoke COM objects that implement the business logic. Further, server **206** may utilize MICROSOFT'S™ Transaction Server (MTS) to access required data stored in database **216** via an interface such as ADO (Active Data Objects), OLE DB (Object Linking and Embedding DataBase), or ODBC (Open DataBase Connectivity).

Generally, these components **200-216** all comprise logic and/or data that is embodied in/or retrievable from device, medium, signal, or carrier, e.g., a data storage device, a data communications device, a remote computer or device coupled to the computer via a network or via another data communications device, etc. Moreover, this logic and/or data, when read, executed, and/or interpreted, results in the steps necessary to implement and/or use the present invention being performed.

Although the terms "user computer", "client computer", and/or "server computer" are referred to herein, it is understood that such computers **202** and **206** may be interchangeable and may further include thin client devices with limited or full processing capabilities, portable devices such as cell phones, notebook computers, pocket computers, multi-touch devices, and/or any other devices with suitable processing, communication, and input/output capability.

Of course, those skilled in the art will recognize that any combination of the above components, or any number of different components, peripherals, and other devices, may be used with computers **202** and **206**.

Embodiments of the invention are implemented as a software application on a client **202** or server computer **206**. Further, as described above, the client **202** or server computer **206** may comprise a thin client device or a portable device that has a multi-touch-based display.

System Architecture

In this section, the design specifications and implementation details of an Auto-Reg (Automatic Registration) system are explained. This system enables users to register their scans automatically and group them into spatially coherent components. The goal is to design a generic, robust and accurate system that can operate on different data types captured from various scenes. FIG. **3** illustrates the logical flow for automatically registering scans in accordance with one or more embodiments of the invention.

Import

Initially, at step **302**, raw scan files are imported to create compressed spherical images-rcc (reality capture compact) files (a proprietary file format available from the assignee of the present application). The rcc representation is highly (memory) efficient and separates the automatic registration from the input file type. Therefore, the processing is performed independently from the raw scan file format.

Preprocessing

Segmentation

Extracting segments from a point cloud needs to be performed well. If good segment extraction is not performed, subsequent steps (e.g., segment matching) may fail or produce poor results. Thus, at step **304** of FIG. **3**, segments are extracted from the imported scan files. Details regarding steps that may be performed during an extraction are described in co-pending patent application Ser. No. 14/536,232 that is incorporated by reference herein.

Embodiments of the invention focus on building information modeling problems/systems. Such a focus relies on the environment to determine features that can then be used during the registration process. More specifically, larger segments (e.g., geometric primitives such as planar segments, cylinders, cones, etc.) may be utilized and provide beneficial results compared to that of smaller segments and/or segments that do not have/contain geometric primitives.

In view of the above, embodiments of the invention utilize the geometry information available in the scene by extracting homogeneous planar regions/segments (and/or segments containing geometric primitives). Extracted segments represent the scene geometry in a compact way that can be exploited to align a scan group.

In order to extract segments, the surface normal may be calculated for each point in the imported scan file. A combination of box-filtering and unconstrained least-squares estimation may be used for fast operation. Then, the extracted normals and spatial distance between points are utilized to group points into similar regions. A region growing method with smoothness constraints may be used to cluster the points with a step to cluster patches with similar orientation and boundaries. The measure of similarity between two points is defined using the angle between their normals and the plane-to-point distance between these points.

Feature Extraction

After the scan files are segmented (i.e., segments are extracted), at step **306**, each segment is analyzed to create/extract features from the segments.

First an orthographic binary image is created by projecting segment members (3D points) onto an orthographic image plane. The pixel size for binary images varies depending on the segment size to normalize the effect of the spatial size of segments. Moreover, keeping only a single point for each pixel eliminates the effect of point density in the later refinement stages. This image is a two-dimensional (2D) representation of a 3D planar segment and by fitting a bounding box around the occupied pixels in this image, approximate 2D dimensions of the segment may be obtained.

At step **308**, the segments are sorted according to their bounding box size since relatively bigger segments are more important for representing the geometry of the scene.

At step **310**, the sorted segments are filtered based on a variety of attributes. The floor and ceiling are detected by using the segment size, segment normal and the z-coordinate of segments. Then the segments that belong to the ceiling and floor are removed from the list. This step ensures that horizontal planes are not used as they are not providing necessary information for the later coarse registration phase.

In view of the above, embodiments of the invention first try and find the floor and ceiling (because they are dominant). It is assumed that the scanner may be a little off (i.e., it is undesirable to rely on the scanner being set up on a tripod or that the surface the scanner is standing on is vertical). By identifying/detecting the floor and ceiling, one may filter and/or reduce the amount of segments/features that need to be examined in later steps.

Accordingly, the segments are separated into two groups: vertical and horizontal segments. Horizontal segments are defined as the segments with surface normals close to the floor's or the ceiling's normal. The rest of the segments are classified as vertical segments. Further, embodiments of the invention may only need/utilize vectors (e.g., the direction of the segment and its center location). Thus, although primitive geometry may be extracted, the geometry may be described as a pure vector that lives somewhere in space with respect to the origin of the scan.

To further reduce the number of segments that are used during later phases, only the large segments (or larger geometry pieces) may be retained. For example, the largest N (50) vertical segments (or other predefined number of segments) are selected as features for registration.

Look-up tables are created for fast processing in the later stages. One or more of the following may be stored in the look-up tables:

- angle between each feature's normal and the z-axis;
- angle between the normals of feature pairs in different look-up tables; and
- a map that stores the indices of features that have a similar angle with the z-axis.

In this regard, since vectors themselves can be matched, the vectors may be used to calculate angles between selected planar elements in the scene. Embodiments of the invention may then match the angles (and not the vectors).

Coarse Registration

As described above, it is not necessary to test all candidates for matching. However, there are some areas where the likely candidates are and such candidates may cluster together. Coarse registration enables the performance of a quicker search since a subset of candidates (i.e., likely candidates) are searched compared to that of all segments.

At step **312**, coarse registration is performed. A coarse transformation between each scan pair (i.e., pair of features) in a scan group (i.e., the filtered group of segments) is calculated. A refinement step (coarse and fine) (i.e., step **314**) follows coarse registration step **312**. The coarse-registration step **312** can be separated into two main components: rotation estimation and translation estimation.

Rotation

Before registration, it is assumed that the scan pair has a common floor and the same floor is detected correctly in both scans. This assumption reduces the search space from a 3D rotation space into a one-dimensional (1D) rotation space which is a rotation around the z-axis or the normal of the floor. Therefore, a single pair of features from two scans can be used to calculate a rotation candidate since the normals of the features are available.

Since calculating a translation and evaluating it for every feature pair from two scans has a huge computational load, a histogram of rotation angle candidates is created and the first M (20) bins (or other predefined number of bins) of this histogram with the maximum/highest number of votes in it are considered (and may be provided/accessed via a look-up table). A histogram of angles from 0 to Thr with bin size of 2 degrees (180 bins in total) is created. From each feature pair that has similar angles with the z-axis, a rotation angle around the z-axis is calculated and the value of the corresponding histogram bin is increased by 1. By doing this, the correct matches are assumed, transformation will focus on similar bins, and random false matches will not create a peak in the histogram. In order to be sure that the correct transformation is not missed, the best (M) bins of the histogram are considered and the translation for the rotation estimates corresponding to these (M) bins is calculated.

Translation

The translation in the z-axis is set to the difference between the floor centers' z-coordinates since it is assumed that the floors are common and approximately planar. Since the translation values are refined later in the process, this assumption does not affect the end results if the floor is detected correctly.

Then the search space is reduced to 2D translations (x-y axis). In order to calculate a 2D translation, two pairs of features are necessary. Therefore every two pairs from two scans are considered. However, since the transformation between two scans is a rigid transformation, the angle between one pair of features must be preserved in the second pair of features. So embodiments of the invention may only consider the second pair if it has a similar angle between its features with the first pair's features' angles. Also, the pairs that have features with approximately parallel normals are removed since they don't provide enough information to estimate a 2D translation.

Accordingly, for each rotation candidate, two pairs of features are selected and the translation is calculated by minimizing the plane-to-point distances between the center point of the features in the source scan and the features in the destination scan, and between the center point of the features in the destination scan and the features in the source scan (a symmetric cost function which removes the effect of scan order). Then each estimate is evaluated by projecting all features in the source scan onto the destination scan and counting the number of features that have a match in the destination scan and vice versa. Two features are matched if they are spatially close and have a similar normal (e.g., within 1-2 degrees). To speed up the evaluation process, the 3D centers of features are projected onto the destination scan's spherical image and only the features that are within a few percent of the image width with respect to the 2D projection point are considered.

In view of the above, in general, there are ten-twenty (10-20) segments that are large and represent major walls, floors, and ceiling. Such large segments often agree with each other on how they match (e.g., rotation and translation). If it is not possible to match the large segments, embodiments of the invention may then proceed to smaller segments (e.g., the side of a door frame) (e.g., by looping through potential segments of a scan to determine if there is something that can constrain an axis or determine a translation/rotation). The use of the smaller segments is similar to searching for a geometric anomaly or characteristic that will enable the matching of segments.

Coarse Refinement

Based on the rotation and translation described above, a set of candidate segments for matching are acquired. To more accurately perform the matching, further refinement is needed.

The coarse translation estimated above is refined by using all the features that are matched. A similar method that is used in the pairwise estimation is used to refine the translations (tx and ty). In this case, instead of using two pairs all of the matched feature pairs are used.

Fine Refinement

In this step, the coarse transformation (rotation+translation) is refined by using the points on the binary image. This step uses more sample points for the ICP (iterative closest point) and results in a better alignment since the increased number of points leads to a more homogeneous fit.

Accordingly, the results from the rotation and translation are used as the basis for extracting sample points from the segments. An ICP method is then performed on the extracted sample points to further match the segments/features.

Scoring the Estimate

Once all of the pairwise matches are acquired, a determination is made regarding which matches are better/the most useful. In this regard, some of the matches may overlap and some matches may conflict. By scoring matches, one can determine which connection/match is the best amongst the possible candidates. Thus, at step **316**, the matches/estimates are scored.

As an example, assume that segment 1 is registered to segment 2, segment 2 is registered to segment 3, segment 4 is registered to segment 5, segment 5 is registered to segment 1, and segment 5 is registered to segment 3. While such matches/registrations may represent a loop, the link between 5 and 1 may be a weak link so it is unknown if a separate cluster should be defined or if the link is part of the overall scanned system. Similarly, 5 may have a weak connection with 3. Thus, the connections between 5 and 1, and 5 and 3 conflict with each other. A determination needs to be made regarding which match is preferred/better. The scoring mechanism of embodiments of the invention determines which match/connection is preferred/should be utilized.

At step **316**, for each selected pairwise transformation, a metric that shows the amount of overlap is calculated (match/no match scores based on visibility). This metric is used as a quality score of the estimated transformation and used when the scans are clustered into a global scene.

In addition, a cycle-based scoring may be used to select locally consistent scan cycles. Each scan triplet (i.e., a match for three) is evaluated by applying all the transformations between each scan. The transformations (edges) are considered as stable if the loop/round-trip around the scans (nodes) ends up in a close proximity of the starting point. In order to create a score from edge cycles, the score of an edge is increased if any "good" cycle passes through that edge.

Growing a Scene—Clustering

As the final step of registration, a global network of scans is created by merging scan nodes with a strong edge (transformation) between them. In other words, at step **318**, segments/scan nodes are clustered together to merge the scans.

In the beginning of merging, only nodes that have edge-cycle scores that are higher than some certain threshold may be considered. In this regard, pairs with a "good" edge between them are sorted using the match/no-match scores. Then the pairs are merged starting from the highest scored pair. If the pair has no connection with other clusters, a new cluster is started. If any edge links two clusters by merging two scans from each cluster, then clusters are also merged.

Final Global Refinement—Bundle Adjustment

In addition to (or as part of the clustering step **318**), further refinement may be performed. In this regard, a full cluster is acquired (as described above) and the connections between scans are known (along with the rotations and translations). Embodiments of the invention attempt to resolve/minimize all errors in the merged scans using a bundle adjustment operation (e.g., all at once). In other words, a bundle adjuster may minimize error over all the scans at once in a non-linear manner. More specifically, points may be matched to planes. As an example, scan **1** may provide a point (e.g., a lower right corner of a door) while scan **2** provides a plane (e.g., the wall). The bundle adjuster will attempt to place the point as close to the plane as possible.

CONCLUSION

This concludes the description of the preferred embodiment of the invention. The following describes some alternative embodiments for accomplishing the present invention. For example, any type of computer, such as a mainframe, minicomputer, or personal computer, or computer configuration, such as a timesharing mainframe, local area network, or standalone personal computer, could be used with the present invention.

In summary, embodiments of the invention provide the ability to register multiple scans to each other. More specifically, a single scan may have important measurements (e.g., between a wall and floor). However, if the user desires to measure the length of an entire building, one scan may not cover the entire distance and the multiple scans must be properly aligned to provide an accurate measurement. Embodiments of the invention register the different scans together so that the user can work with an entire building instead of a single scan. Such a process must determine which elements/parts of a scan match with elements/parts of another scan. To provide such capabilities, the scanned scenes are segmented (by extracting segments) and features are extracted from the segments. The segments are then sorted and filtered to reduce the number of segments that are compared to each other. The features within the sorted and filtered segments are compared to each other based on rotation and translation operations (resulting in pairs of matching features). The pairs of matching features are refined based on all of the matched features, and further refined by comparing the points within the features. The refined matching pairs are then scored and clustered based on the score to merge scans together.

The foregoing description of the preferred embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

What is claimed is:

1. A computer-implemented method for merging multiple point cloud scans, comprising:

(a) importing a first raw scan file and a second raw scan file, wherein each raw scan file comprises multiple points;

(b) segmenting the first raw scan file and the second raw scan file by extracting first segments from the first raw scan file and second segments from the second raw scan file;

(c) extracting first features from the first segments and second features from the second segments;

(d) coarsely registering one or more of the first features to one or more of the second features to acquire a set of candidate matching feature pairs;

(e) refining the registering based on all of the candidate matching feature pairs;

(f) further refining the registering by:

(1) extracting sample points from the extracted first segments and the extracted second segments based on the registering; and

(2) utilizing the extracted sample points to refine the candidate matching feature pairs;

(g) scoring the candidate matching feature pairs; and

(h) merging the first raw scan file with the second raw scan file based on the scoring.

2. The computer-implemented method of claim **1**, wherein the first raw scan file and the second raw scan file are processed to create a first compressed spherical image file and a second compressed spherical image file respectively.

3. The computer-implemented method of claim **1**, wherein the extracted first segments and extracted second segments comprise homogeneous planar regions.

4. The computer-implemented method of claim **1**, wherein the extracting the first segments comprises:

calculating a surface normal for each of the one or more points in the first raw scan file; and

grouping, based on the calculated surface normal and a spatial distance between each of the one or more points, the one or more points into one or more regions.

5. The computer-implemented method of claim **4**, wherein the grouping comprises:

clustering the one or more points using a region growing method; and

grouping the one or more points within a cluster based on a measure of similarity that is defined using an angle between the surface normal for each of the one or more points and the spatial distance that is defined as a plane-to-point distance between the one or more points.

6. The computer-implemented method of claim **1**, wherein the extracting the first features and the second features comprises:

creating an orthographic binary image by projecting the one or more points from the first segments and the second segments onto an orthographic image plane;

fitting, on the orthographic image plane, a first bounding box around pixels corresponding to one or more of the first segments and a second bounding box around pixels corresponding to one or more of the second segments;

determining two-dimensional (2D) dimensions of the one or more first segments and the one or more second segments based on corresponding bounding boxes;

sorting the one or more first segments and the one or more second segments based on sizes of corresponding bounding boxes; and

filtering the sorted one or more first segments and the one or more second segments.

7. The computer-implemented method of claim **6**, wherein the filtering comprises:

filtering out floor and ceiling segments based on segment size, segment normal, and z-coordinates.

8. The computer-implemented method of claim **6**, wherein:

the filtering comprises classifying each of the sorted one or more first segments and the one or more second segments as a vertical segment or a horizontal segment; and

selecting a set of the vertical segments that are largest as features for registration.

9. The computer-implemented method of claim **1**, wherein the coarsely registering comprises:

(a) estimating a rotation comprising:

(i) determining a common floor in the first raw scan file and the second raw scan file, thereby reducing a search space from a three-dimensional (3D) rotation space into a one-dimensional (1D) rotation space comprising a rotation around a z-axis;

(ii) creating a histogram comprising histogram bins that correspond to rotation candidate angles, wherein each rotation candidate angle is based on a single pair of features, wherein the pair of features comprises one of the extracted first features paired with one of the extracted second features; and

(ii) considering a predefined number of the histogram bins; and

(b) estimating a translation of the considered predefined number of histogram bins comprising:

(i) determining a difference between z-coordinates of centers of the common floor from the first raw scan file and the second raw scan file.

10. The computer-implemented method of claim **9**, wherein the creating the histogram comprises:

creating the histogram bins for angles from 0 to 2π, wherein the histogram bins are of a predefined bin size based on a number of degrees;

for each single pair of features having corresponding angles with the z-axis, computing a rotation angle around the z-axis and increasing a value of the histogram bin corresponding to the computed rotation angle; and

wherein the histogram bins considered are selected from the bins having the highest values.

11. The computer-implemented method of claim **9**, wherein the estimating the translation further comprises:

for each rotation candidate angle in the considered predefined number of histogram bins:

(i) selecting two pairs of features;

(ii) calculating an estimated translation by minimizing a plane-to-point distance between a center point of the first feature and a center point of the second feature in each of the two pairs of features;

(iii) evaluating the estimated translation by:

(1) projecting all of the first features onto the second raw scan file; and

(2) counting a number of the first features that have a match on the second raw scan file.

12. The computer-implemented method of claim **1**, wherein the further matching the first segments to the second segments based on the extracted sample points, is based on iterative closest point (ICP) processing.

13. The computer-implemented method of claim **1**, wherein the scoring comprises:

computing an amount of overlap between the first feature and the second feature of each candidate matching feature pair.

14. The computer-implemented method of claim **1**, wherein the scoring comprises a cycle-based scoring to select locally consistent scan cycles.

15. A non-transitory computer readable storage medium encoded with computer program instructions which when accessed by a computer cause the computer to load the program instructions to a memory therein creating a special purpose data structure causing the computer to operate as a specially programmed computer, executing a method of merging multiple point cloud scans, comprising:

(a) importing, in the specially programmed computer, a first raw scan file and a second raw scan file, wherein each raw scan file comprises multiple points;

(b) segmenting, in the specially programmed computer, the first raw scan file and the second raw scan file by extracting first segments from the first raw scan file and second segments from the second raw scan file;

(c) extracting, in the specially programmed computer, first features from the first segments and second features from the second segments;

(d) coarsely registering, in the specially programmed computer, one or more of the first features to one or more of the second features to acquire a set of candidate matching feature pairs;

(e) refining, in the specially programmed computer, the registering based on all of the candidate matching feature pairs;

(f) further refining, in the specially programmed computer, the registering by:

(1) extracting sample points from the extracted first segments and the extracted second segments based on the registering; and

(2) utilizing the extracted sample points to refine the candidate matching feature pairs;

(g) scoring, in the specially programmed computer, the candidate matching feature pairs; and

(h) merging, in the specially programmed computer, the first raw scan file with the second raw scan file based on the scoring.

16. The non-transitory computer readable storage medium of claim **15**, wherein the first raw scan file and the second raw scan file are processed, in the specially programmed computer, to create a first compressed spherical image file and a second compressed spherical image file respectively.

17. The non-transitory computer readable storage medium of claim **15**, wherein the extracted first segments and extracted second segments comprise homogeneous planar regions.

18. The non-transitory computer readable storage medium of claim **15**, wherein the extracting the first segments comprises:

calculating, in the specially programmed computer, a surface normal for each of the one or more points in the first raw scan file; and

grouping, in the specially programmed computer, based on the calculated surface normal and a spatial distance between each of the one or more points, the one or more points into one or more regions.

19. The non-transitory computer readable storage medium of claim **18**, wherein the grouping comprises:

clustering, in the specially programmed computer, the one or more points using a region growing method; and

grouping, in the specially programmed computer, the one or more points within a cluster based on a measure of similarity that is defined using an angle between the surface normal for each of the one or more points and the spatial distance that is defined as a plane-to-point distance between the one or more points.

20. The non-transitory computer readable storage medium of claim **15**, wherein the extracting the first features and the second features comprises:

creating, in the specially programmed computer, an orthographic binary image by projecting the one or more points from the first segments and the second segments onto an orthographic image plane;

fitting, in the specially programmed computer, on the orthographic image plane, a first bounding box around pixels corresponding to one or more of the first segments and a second bounding box around pixels corresponding to one or more of the second segments;

determining, in the specially programmed computer, two-dimensional (2D) dimensions of the one or more first segments and the one or more second segments based on corresponding bounding boxes;

sorting, in the specially programmed computer, the one or more first segments and the one or more second segments based on sizes of corresponding bounding boxes; and

filtering, in the specially programmed computer, the sorted one or more first segments and the one or more second segments.

21. The non-transitory computer readable storage medium of claim **20**, wherein the filtering comprises:

filtering, in the specially programmed computer, out floor and ceiling segments based on segment size, segment normal, and z-coordinates.

22. The non-transitory computer readable storage medium of claim **20**, wherein:

the filtering comprises classifying, in the specially programmed computer, each of the sorted one or more first segments and the one or more second segments as a vertical segment or a horizontal segment; and

selecting, in the specially programmed computer, a set of the vertical segments that are largest as features for registration.

23. The non-transitory computer readable storage medium of claim **15**, wherein the coarsely registering comprises:

(a) estimating, in the specially programmed computer, a rotation comprising:

(i) determining a common floor in the first raw scan file and the second raw scan file, thereby reducing a search space from a three-dimensional (3D) rotation space into a one-dimensional (1D) rotation space comprising a rotation around a z-axis;

(ii) creating a histogram comprising histogram bins that correspond to rotation candidate angles, wherein each rotation candidate angle is based on a single pair of features, wherein the pair of features comprises one of the extracted first features paired with one of the extracted second features; and

(ii) considering a predefined number of the histogram bins; and

(b) estimating, in the specially programmed computer, a translation of the considered predefined number of histogram bins comprising:

(i) determining a difference between z-coordinates of centers of the common floor from the first raw scan file and the second raw scan file.

24. The non-transitory computer readable storage medium of claim **23**, wherein the creating the histogram comprises:

creating, in the specially programmed computer, the histogram bins for angles from 0 to 2π, wherein the histogram bins are of a predefined bin size based on a number of degrees;

for each single pair of features having corresponding angles with the z-axis, computing, in the specially programmed computer, a rotation angle around the z-axis and increasing a value of the histogram bin corresponding to the computed rotation angle; and

wherein the histogram bins considered are selected from the bins having the highest values.

25. The non-transitory computer readable storage medium of claim **23**, wherein the estimating the translation further comprises:

for each rotation candidate angle in the considered predefined number of histogram bins:

(i) selecting two pairs of features;

(ii) calculating an estimated translation by minimizing a plane-to-point distance between a center point of the first feature and a center point of the second feature in each of the two pairs of features;

(iii) evaluating the estimated translation by:

(1) projecting all of the first features onto the second raw scan file; and

(2) counting a number of the first features that have a match on the second raw scan file.

26. The non-transitory computer readable storage medium of claim **15**, wherein the further matching the first segments to the second segments based on the extracted sample points, is based on iterative closest point (ICP) processing.

27. The non-transitory computer readable storage medium of claim **15**, wherein the scoring comprises:

computing, in the specially programmed computer, an amount of overlap between the first feature and the second feature of each candidate matching feature pair.

28. The non-transitory computer readable storage medium of claim **15**, wherein the scoring comprises a cycle-based scoring to select locally consistent scan cycles.

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